Assessing Forest Height Retrieval from Commercial X-band SAR Products

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Aims of this study

• To study trends in “vegetation bias” in airborne SAR-retrieved height over managed plantation forest in the UK.
• Compare this height data with actual tree heights to quantify relationship.
• To assess whether this met the +/-10% requirement.
• Model the response for different forest conditions.
Context

- Height estimation is valuable for forest management, carbon accounting, visualisation.
- InSAR or Lidar?
- Intermap NEXTMAP Britain data set – commercial airborne SAR digital elevation data for mainland UK.
- Commercial data sets increasingly available.
SAR Interferometry
Interferometric Synthetic Aperture Radar (INSAR).

Consists of two X-band radar antennas mounted in a Learjet.

Typically flown at 6000m (~20,000 ft), and acquires a 10Km wide swath of 1.25m resolution radar data at a rate of up to 100Km² / hour.

Stated DEM vertical accuracy of <2m RMSE.
Test sites species

- Sitka spruce (Picea sitchensis)
- Norway spruce (Picea abies)
- Japanese larch (Larix kaempferi)
- Western hemlock (Tsuga heterophylla)
- Scots pine (Pinus sylvestris)
Effect of penetration and attenuation on height retrieval

<table>
<thead>
<tr>
<th>Radar Band</th>
<th>Frequency (GHz)</th>
<th>Wavelength (cm)</th>
<th>Typically (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>8.0 - 12.5</td>
<td>2.4 - 3.8</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>4.8 - 8.0</td>
<td>3.8 - 7.5</td>
<td>5.6</td>
</tr>
<tr>
<td>L</td>
<td>4.8 - 8.0</td>
<td>15.0 - 30.0</td>
<td>23.5</td>
</tr>
<tr>
<td>P</td>
<td>0.3 - 1.0</td>
<td>30.0 - 100.0</td>
<td>75</td>
</tr>
</tbody>
</table>
• Ideal situation:

\[ H_{\text{Canopy}} = H_{\text{Observed}} - H_{\text{Ground}} \]

• Actual situation:

\[ H_{\text{Apparent}} = H_{\text{X-band}} - H_{\text{Ground}} \]
Digital surface model (DSM) – Digital Terrain Model (DTM)
Effect of DTM interpolation limitation on height retrieval using DSM-DTM
Overall RMSE over open ground = 1.38m standard deviation 1.05m
Overall RMSE under forest cover = 13.51m standard deviation 2.21m
DSM – Ordnance Survey DEM (OSDEM)
Forest height retrieval \( (H_{\text{Tree}} = H_{\text{DSM}} - H_{\text{OSDEM}}) \)

- Measured Top Height vs Retrieved Top Height
- Obs. = 59, Pearson’s R = 0.79.
- Average error of 7.23m (34.73%)

Note: Kielder (○) data were collected independently of Kielder (□).
Modelling height retrieval

- Retrieved height from phase coherence
  - $B/\lambda = 32$
  - Inc. angle = 40deg
  - Density: 816 trees/ha
  - Tree height: 25 m
  - HV (+) and VV (*) polarisations

- Retrieved height from phase coherence
  - $B/\lambda = 32$
  - Inc. angle = 40deg
  - Density: 156 trees/ha
  - Tree height: 25 m
  - HV (+) and VV (*) polarisations
Edge effects at increasing tree height

- Extent of area affected increases as tree height increases

- HH > HV

Ground scattering HH > HV

HHH < HHV
Edge effects at varying ground slope

Extent of area affected:
- Increases as slopes increase upward
- Decrease as slopes increase downward
Edge effects at varying ground slope

Extent of area affected:
- Increases as slopes increases upward
- Decrease as slopes increases downward

$$y = \frac{h}{\tan(\theta \pm \alpha)}$$
Height retrieval results (all species)

Measured Top Height vs Retrieved Top Height

- Affric
- Wales
- Kielder
- Aber

$y = 0.68x$
$R^2 = 0.62$
Single species retrieval (sitka spruce)

Measured top height v Retrieved top height

- Wales
- Kielder
- Aberfoyle

\[ y = 0.82x \quad R^2 = 0.90 \]
\[ y = 0.79x \quad R^2 = 0.84 \]
\[ y = 0.76x \quad R^2 = 0.94 \]
Conclusions

• There is a vegetation bias in DSM and DTM products proportional to the canopy height (and tree number density) of forested areas.

• Using a ground DEM and species info we can estimate canopy heights to about +/-12%.

• Errors are related to species and tree number density.

• Future: TerraSAR-X tandem mission X-band InSAR from space
Acknowledgements

• Intermap Technologies (data provision)
• Royal Institute of Chartered Surveyors
• Carnegie Trust for the Universities of Scotland
• International Federation of Surveyors
• Edinburgh Earth Observatory
• University of Edinburgh